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Investigating the Impact of Usability on Energy Efficiency of Web-based Personal Health Records

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Abstract Usability plays an important role in eHealth applications for their widespread adoption. These software systems have been studied in depth in the literature from this perspective. However, the energy consumption of information systems in the eHealth domain lacks comprehensive research. In this paper, the relationship between the energy consumption of the main components of a PC and the usability evaluations of graphical user interfaces (GUI) were studied in client applications. For this purpose, personal health records (PHR) were used as a case study. A set of 4 web-based PHRs were evaluated with the performance of 20 common tasks in the aforementioned systems. The usability evaluations were carried out by 4 experts. A total of 8 heuristics particularly designed for electronic health record systems and based on the Nielsen usability heuristics were

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employed. The instantaneous energy values of the power supply and the monitor were collected with an energy consumption measuring equipment. As a result, the following significant correlations were found: (1) in NoMoreClipboard between the Memory heuristic and the power supply ($r_s = 0.495, p = 0.044$), and the Minimalist heuristic and the monitor ($r_s = -0.513, p = 0.035$). In PatientsLikeMe between the Minimalist heuristic and the power supply ($r_s = -0.479, p = 0.083$), as well as in the Error heuristic and the power supply ($r_s = -0.638, p = 0.014$). Finally, in Health Companion between the Match heuristic and the power supply ($r_s = -0.481, p = 0.043$), and the Error heuristic and the power supply again ($r_s = -0.602, p = 0.008$). Apart from that, the tasks were divided into those with excellent and fair usability. Those tasks with high usability scores were evaluated to detect whether they also had low energy consumption during task performance. Significant differences were found in PatientsLikeMe with respect to the Error heuristic and the power supply (212.39 ± 18.85W). Significant differences were also found in Health Companion with respect to the Match heuristic and the power supply (199.91 ± 7.19W). The results were discussed to reveal the fundamentals of how implementing usability can impact on energy costs when running client applications.

Keywords Energy Efficiency · Usability · Software Sustainability · Green Software · Personal Health Records · eHealth.

1 Introduction

Personal health records (PHRs) have the potential to empower patients by allowing them to access and manage their health data [1,2]. The adoption of PHRs by patients can improve the quality of healthcare service and decrease demand particularly if they provide users with educational content about their conditions [3]. Users of eHealth applications often share their health data with healthcare providers [4] but are usually concerned with their health data privacy and the usability of these applications [5]. Users tend to find difficulties to locate important health information in web-based eHealth solutions due to poor usability [6]. Usability has been identified an important factor in PHRs to improve users' confidence in its use [7]. Poor usability in PHRs is linked to users' difficulty to take advantage of applications, which do not provide good utility to users [8].

There is a wide range of approaches to evaluate usability in eHealth applications [9], such as: heuristic evaluation [10], focus groups [11], checklists [12], cognitive walkthrough [13] and think-aloud protocol [14]. The usability evaluation approaches are generally categorized as *expert-based* inspection or *user-based* testing methods [15]. Heuristic evaluation and think-aloud are considered the most frequent examples of these two methods, respectively [16]. The use of heuristics has been extensively investigated in literature [17,18]. It is very common to find a set of heuristic proposed for specific domains. Most studies, however, use the Nielsen usability heuristic [19]. They are widely adopted to assess usability and are considered a reference, particularly in evaluating usability of websites [17].

There has been an increase of interest among researchers about PHRs due to their promising role in providing sustainable eHealth services [20]. Software sustainability is an important challenge for digital healthcare industry [21]. Software has become ubiquitous in today's society and its massive use is beginning to represent a problem for the environment and sustainable development; sustainability, therefore, must become central to the design of software systems [22]. Sustainable software, however, is a very wide and complex concept [23] with a multidimensional and multidisciplinary nature [24]. According to the Karlskrona Manifesto [24], up to five dimensions can be identified in sustainable software systems: environmental, social, economic, technical and individual. Two important aspects of software sustainability are energy consumption and energy efficiency [25–27]. Energy consumption is about the amount of power consumed to operate a software system, while energy efficiency is about the consumption of as little energy as possible in a software system. Energy efficiency is becoming important in eHealth solutions as the amount of health data generated and used in these solutions keeps increasing [28].

The aim of this paper is to analyze the relationships between usability scores of GUIs and power consumption measurements of the monitor and the power supply. At this end, web-based PHRs allowed to study the aforementioned relationship. This paper builds on the results of some previous studies [29, 30], and uses an empirical data collection approach. Moreover, a formal analysis process based on statistical techniques was employed. A particular equipment with sensors was used to obtain instantaneous measurements of energy consumption. In addition, a systematic usability evaluation method based on Nielsen's usability heuristics (`nngroup.com/articles/ten-usability-heuristics`) allowed us to provide new evidence on the interplay between usability of the GUIs and power consumption in client applications. The main findings of this paper shed light to the development of recommendations that allow to generate client applications that are energy-aware. Despite the results arose from the study of PHRs, the knowledge extracted from the experiment can be harnessed for the design of a wide variety of webpages focused on topics like banking, blogs, forum, e-commerce and social networks. The rest of this paper is organized as follows: Section 2 describes the materials and methods used in the study. Section 3 shows the empirical results linked to the research questions of this work. Section 4 includes recommendations based on the results. Finally, Section 5 concludes with principal findings and future works.

2 Materials and Methods

This section presents the research questions and methods used to: (1) select the PHRs, (2) evaluate the usability of the PHRs, and (3) measure the PHRs energy consumption.

2.1 Research questions

This study aims to answer 2 research questions that were posed for a better understanding of the topic proposed in this paper.

- **RQ 1:** Is a higher score of the usability heuristics related to a lower power consumption of the PC components?
- **RQ 2:** Is higher usability heuristics score related to lower power consumption of PC components?

2.2 Selection protocol

The main stages in the selection protocol of the PHRs were based on a previous study [31]. A basic search string consisting of the terms *"PHR providers" OR "PHR website"* was employed in the following databases: *ACM Digital Library, IEEE Digital Library, Medline and ScienceDirect.* The papers found in the databases were explored carefully to detect PHRs candidates for the study. The checklist defined by the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) group [32] was followed for a better accuracy and impartiality in the manuscripts selection process. An inclusion criterion (IC) was established *(i.e.: PHRs had to be free and web-based)* to collect a primary group of PHRs. A total of 19 PHRs met the IC. The following set of exclusion criteria (EC) were applied to the 19 candidate PHRs.

EC1 Non-available PHRs
EC2 PHRs that are not for free
EC3 Sign up not possible
EC4 Mal-functioning PHRs
EC5 PHRs available only in EEUU
EC6 Low-popularity PHRs

EC6 was applied through Alexa website (`alexa.com/siteinfo`), which is a sorting online mechanism to verify visits in web portals. A scoring threshold of 10 million determined the low-popularity of the websites. As a result, *HealthyCircles*, *Telemedical*, *Dr. I-Net*, *MedsFile*, *ZebraHealth*, *EMRySTICK* and *Dlife* were discarded because of EC1, *myMediConnect* and *Juniper Health* due to EC2, *RememberItNow!* by EC3, *WebMD HealthManager* by EC4, and *PatientPower* by EC5. More PHRs were discarded in the selection process, applying EC6. *My Health Folders* and *My Doclopedia* fulfilled the aforementioned criterion. The Alexa ranking mark exposed a very low popularity of these portals compared with the established threshold. The steps to choose the PHRs were established in January 2018 and corroborated in October 2020. On the latter date, the grey literature was explored using a search engine to find additional personal health systems to study. No new PHRs were observed that followed the inclusion and exclusion criteria. An evaluation of the main functionalities of the PHRs allowed to select the PHRs of interest [31]: *HealthVet*, *PatientsLikeMe*, *Health Companion*, and *NoMoreClipBoard*. Figure 1 summarises the selection process. All the PHRs selected had key features that distinguished them, covering a wide range of functionalities presented in Table 1.

2.3 Evaluation method

The PHRs were assessed from two important perspectives in software, which are (1) usability and (2) power consumption.

2.3.1 Usability

According to ISO/IEC 25010:2011 usability is *"the degree to which a product or system can be used by specified users to achieve specified goals with effectiveness,*

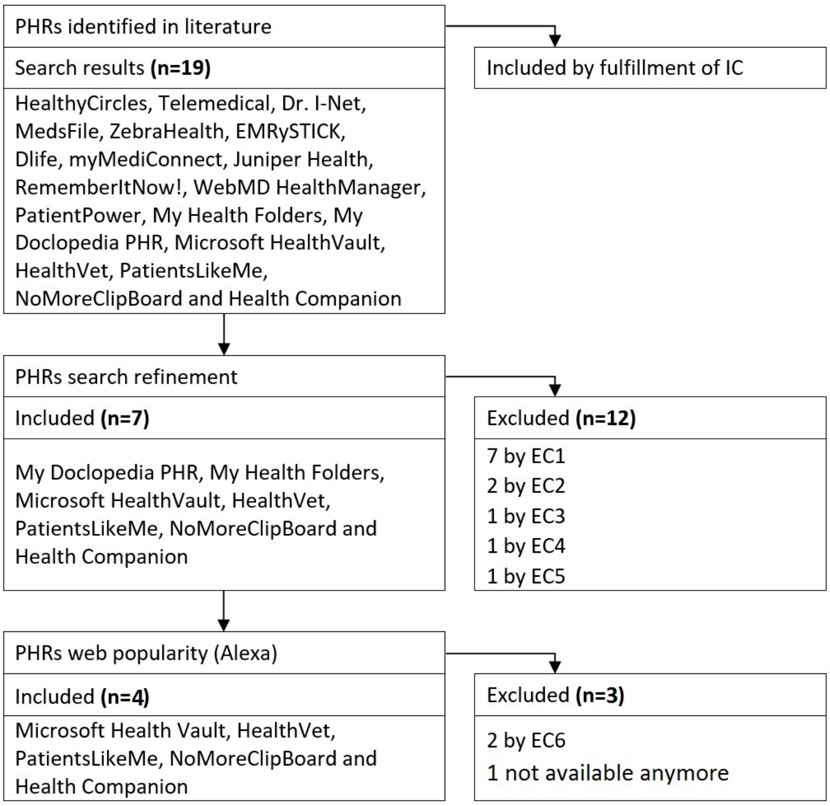

Fig. 1 PRISMA flow chart. Acronyms: Personal Health Record (PHR), Inclusion Criterion (IC), and Exclusion Criterion (EC)

Table 1 PHRs' overview

HealthVet `myhealth.va.gov`	PHRs destined to US Veterans of the VA Health Care System.
PatientsLikeMe `patientslikeme.com`	Social network oriented.
NoMoreClipboard `nomoreclipboard.com`	Approved for both outpatient and inpatient use by USA authorities.
Health Companion `healthcompanion.com`	Verified for privacy and security matters by USA authorities.

efficiency and satisfaction in a specified context of use." In this standard six sub-characteristics are linked to the characteristic *Usability* [33]:

– **Appropriateness recognizability:** degree of recognition of the suitability of a product or system for the needs of users.

– **Learnability:** degree of suitability that a product or system is used for specific learning objectives with effectiveness, efficiency, absence of risk and satisfaction in a specific context.
– **Operability:** ease of use and control of a product or system.
– **User error protection:** the system warns users against errors.
– **User interface aesthetics:** pleasant and satisfactory interaction with the user interface.
– **Accessibility:** Ease of use of a product or system by users with a wide range of characteristics and capabilities in order to achieve a specific objective in a given context.

In this study, a set of usability heuristics based on the 10 usability heuristics for user interface design by Nielsen were employed (`nngroup.com/articles/ten-usability-heuristics`). The heuristics were proposed for usability assessment of medical information systems [34]. A set of 2 questions was derived from each heuristic as a checklist. The usability assessment of the selected PHRs were harmonized with the checklist.

A total of 4 experts assessed usability. According to Neilsen [35] when the number of auditors are between 4 and 5 the ratio of benefits to cost is maximized. With 4 auditors, the proportion of usability problems covered is around 70% [35]. The heuristics used in this study with their associated questions are presented below. Table 2 presents the relationship between the aforementioned usability subcharacteristics and the Neilsen's based heuristics.

– **Match:** ensure task components match user's mental model.
  h1q1: *Are the PHR's terminology exposed in a familiar way to the user?*
  h1q2: *Are PHR's screens presented in the most logical way?*
– **Visibility:** allow the user to know how the system is working.
  h2q1: *Is there any visual feedback highlighting which choices are clickable?*
  h2q2: *Is there any observable delay in the response time of the system?*
– **Memory:** provide the user with the information needed to carry out a task.
  h3q1: *Is there enough information displayed at each step in the tasks?*
  h3q2: *Is there a default choice in the data menus?*
– **Minimalist:** there is unnecessary information displayed on the screen.
  h4q1: *is the information duplicated eliminated?*
  h4q2: *is is possible to display or hide information (i.e., expanding, collapsing lists)?*
– **Error:** help user solve current problem.
  h5q1: *Is the user warned that an error is about to be made?*
  h5q2: *Do text box warn user of error severity?*
– **Consistency:** the user can visually distinguish sections of the interface.
  h6q1: *Are there consistently named widgets in the PHR that perform the same action?*
  h6q2: *Are menu names consistent in grammatical style and terminology?*
– **Control:** avoid the action cannot be canceled.
  h7q1: *is it possible to cancel an action of a task?*
  h7q2: *is it easy to reverse the actions by the user?*
– **Flexibility:** possibility to reuse an action history.
  h8q1: *Are there shortcuts for high-frequency actions?*
  h8q2: *Is it possible to substitute unnecessary actions with templates?*

Table 2 Characteristics in ISO/IEC 25010 vs Heuristics. Acronym: Appropriateness recognizability (AR), User Error Protection (UEP), and User Interface Aesthetics (UIA)

	AR	Learnability	Operability	UEP	UIA	Accessibility
H1. Match	X	X	X			X
H2. Visibility	X		X			
H3. Memory		X		X		X
H4. Minimalist			X		X	X
H5. Error		X	X	X		
H6. Consistency	X				X	
H7. Control		X	X	X		
H8. Flexibility		X	X			X

The PHRs were analysed with the performance of a set of tasks proposed in this study. The tasks were identified considering common needs detected for a proper interaction among different profiles of use [36,37]. Moreover, the guidelines of the American Health Information Management Association (AHIMA) were followed for their definition [38]. Table 3 presents typical actions that can be performed in a PHR. For each one of the tasks the heuristics were scored on a Likert scale, ranging from 0, not supported; 1, very little supported; 2, little supported; 3, supported; 4, well supported and 5, very well supported.

Table 3 Typical tasks identified in a PHR

TASK 01: Registration
TASK 02: System access
TASK 03: Add profile
TASK 04: View profile
TASK 05: Manage permissions to 3rd parties
TASK 06: Add family history
TASK 07: Add medication
TASK 08: Add new allergy
TASK 09: Add vaccine
TASK 10: Add disease
TASK 11: View medications
TASK 12: Print report
TASK 13: View glucose evolution
TASK 14: Search for information about conditions
TASK 15: Export health info
TASK 16: Schedule appointments and medication reminder
TASK 17: Send suggestion/contact
TASK 18: See privacy policy
TASK 19: Exit
TASK 20: Forgotten password

2.3.2 Energy efficiency

Tasks presented in Table 3 were performed while measuring each PHR's power consumption. To do so, the Energy Efficient Tester (EET) [39] was employed. This equipment can obtain instant energy measurements of the monitor and power supply. The EET device was connected to a Philips 170S6FS TFT-LCD monitor and a host machine with the following PC components:

- **Motherboard:** GigaByte^{TM} GA-8I945P-G
- **Processor:** Intel Pentium^{TM} D @ 3.0GHz
- **RAM memory:** A set of 2 modules of 1GB DDR2 @ 533 MHz
- **Hard disk drive:** Samsung^{TM} SP2004C 200GB 7500 rpm
- **Graphics card:** Nvidia GeForce^{TM} GTS 8600
- **Power supply:** Aopen^{TM} Z350-08FC 350 W

The presence of outliers in the data was checked. Per each task the average of the collection of power measurements from the power supply and the monitor was calculated. The tasks were performed five times so the results were averaged again to smooth any peak of energy consumption. The experiment was run with a host machine in which Microsoft Windows 7 Professional^{TM} was installed, and deactivating all the background accessible processes to reduce the basic power consumption of the operating system. In this machine Chrome^{TM} browser version 62 was employed to run the client applications.

3 Results

A set of 10 variables were identified: 8 variables for the heuristics and 2 for the energy consumption of the monitor and power supply. The length of the variables was of 20 values obtained from the 20 tasks performed in a PHR. For the usability scores, an average result was calculate for each heuristic from the values each auditor inputted in the system. In some cases, some of the tasks were not available in the PHR evaluated. The data collected for the study can be checked at `umubox.um.es/index.php/s/G7UNdhsNMWjF1cW`.

Since the usability assessments were ordinal values while the power consumption figures were continuous, the Pearson's and the Spearman's correlation allowed to obtain the relationships between both variables. The calculation was performed with the resulting 16 pairs of combinations between the 8 columns of usability assessments and the 2 columns of power measurements.

3.1 RQ 1. Is a higher score of the usability heuristics related to a lower power consumption of the PC components?

The results in HealthVet showed that no significant correlations appeared between usability evaluations and power consumption. Table 4 presents the correlation between HealthVet's usability heuristics scores and power consumption.

Concerning the results related to the PHR NoMoreClipboard, several important correlations were found between h3-memory and power source ($r_s = 0.495, p = 0.044$), and h4-minimalist and monitor ($r_s = -0.513, p = 0.035$). Another moderate correlation was found between h8-flexibility and power supply ($r_s = -0.457, p = 0.065$). The results are showed in Table 5.

The results related to the PHR PatientsLikeMe showed a strong correlation between h5-error and power supply ($r_s = -0.638, p = 0.014$). It is worth noting that another moderate correlation appeared between h4-minimalist and the same PC component ($r_s = -0.479, p = 0.083$). Results are displayed in Table 6.

Finally, three important correlations were presented in Health Companion: between h1-match and power source ($r_s = -0.481, p = 0.122$), h5-error and power

Table 4 Correlations of usability heuristics and power consumption (I)

	HealthVet			
	Monitor		**Power supply**	
	r_s	p	r_s	p
H1	0.120	0.636	0.300	0.226
H2	0.367	0.134	-0.193	0.443
H3	0.159	0.529	-0.319	0.198
H4	-0.162	0.521	-0.015	0.953
H5	-0.010	0.970	-0.206	0.412
H6	-0.266	0.286	-0.080	0.751
H7	-0.341	0.166	0.058	0.819
H8	-0.230	0.358	-0.021	0.933

Table 5 Correlations of usability heuristics vs power consumption (II)

	NoMoreClipboard			
	Monitor		**Power supply**	
	r_s	p	r_s	p
H1	-0.258	0.317	-0.208	0.423
H2	-0.229	0.376	-0.034	0.896
H3	0.039	0.881	*0.495*	*0.044*
H4	*-0.513*	*0.035*	-0.077	0.770
H5	0.090	0.731	-0.223	0.390
H6	0.036	0.890	-0.086	0.743
H7	-0.352	0.165	-0.273	0.289
H8	-0.244	0.346	*-0.457*	*0.065*

Table 6 Correlations of usability heuristics vs power consumption (III)

	PatientsLikeMe			
	Monitor		**Power supply**	
	r_s	p	r_s	p
H1	0.108	0.714	-0.154	0.599
H2	0.132	0.652	-0.200	0.493
H3	0.421	0.134	-0.256	0.377
H4	0.207	0.477	*-0.479*	*0.083*
H5	0.104	0.723	*-0.638*	*0.014*
H6	-0.351	0.218	-0.074	0.801
H7	-0.315	0.273	-0.158	0.589
H8	0.188	0.521	-0.328	0.252

supply ($r_s = -0.602, p = 0.008$), and between h6-consistency and power supply again ($r_s = 0.617, p = 0.006$). These results appear in Table 7.

3.2 RQ 2. Is higher usability heuristics score related to lower power consumption of PC components?

The tasks in each one of the PHRs were divided into those with excellent and fair usability. A threshold was established with the median of the values in each heuristic. The aforementioned value allowed to determine in which usability group

Table 7 Correlations of usability heuristics vs power consumption (IV)

	Health Companion			
	Monitor		Power supply	
	r_s	p	r_s	p
H1	0.122	0.629	*-0.481*	*0.043*
H2	0.055	0.827	-0.065	0.798
H3	-0.071	0.779	0.381	0.119
H4	-0.252	0.312	0.256	0.304
H5	-0.083	0.743	*-0.602*	*0.008*
H6	0.023	0.928	*0.617*	*0.006*
H7	-0.010	0.968	0.241	0.335
H8	-0.016	0.950	0.109	0.666

the task had to be placed. The division of the tasks concerning excellent or fair usability can be checked at `umubox.um.es/index.php/s/G7UNdhsNMWjF1cW`.

As showed in Table 8 no significant differences were found in HealthVet concerning RQ2.

Table 8 Analysing the effect of usability on power consumption by a T-student test (I)

	HealthVet			
	Monitor		Power supply	
	T(df)	p	*T(df)*	p
H1	T(16)= 0.728	0.477	T(16)= 1.976	0.066
H2	T(16)= 0.616	0.547	T(16)=-0.499	0.624
H3	T(15,43)=2.051	0.058	T(16)=-1.831	0.086
H4	T(16)=-0.864	0.401	T(16)=-0.251	0.805
H5	T(16)=-0.821	0.424	T(16)=-0.393	0.699
H6	T(16)=-0.707	0.490	T(16)=-1.100	0.288
H7	T(16)=-0.247	0.808	T(16)= 0.685	0.503
H8	T(16)= 0.345	0.783	T(16)=-0.127	0.859

There were no significant differences for NoMoreClipboard either (see Table 9).

Table 9 Analysing the effect of usability on power consumption by a T-student test (II)

	NoMoreClipboard			
	Monitor		Power supply	
	T(df)	p	*T(df)*	p
H1	T(15)=-1.038	0.316	T(15)= 0.206	0.839
H2	T(15)=-2.124	0.051	T(15)= 0.270	0.791
H3	T(15)=-0.332	0.744	T(15)= 1.784	0.095
H4	T(15)=-1.740	0.102	T(15)= 0.929	0.368
H5	T(15)= 0.555	0.587	T(15)=-0.905	0.380
H6	T(2,21)=-0.663	0.570	T(15)= 0.610	0.551
H7	T(15)=-1.311	0.210	T(15)=-1.047	0.312
H8	T(15)= 0.040	0.969	T(7,97)=-2.056	0.074

Significant differences were found in PatientsLikeMe. The results depicted that the tasks that were considered to have excellent usability with respect to h5-error, required less energy from the power supply, 212.39 ± 18.85 W. The statistical results are showed in Table 10.

Table 10 Analysing the effect of usability on power consumption by a T-student test (III)

	PatientsLikeMe			
	Monitor		**Power supply**	
	T(df)	*p*	*T(df)*	*p*
H1	T(12)=-1.151	0.272	T(12)= 0.881	0.396
H2	T(12)=-1.063	0.309	T(12)= 0.617	0.548
H3	T(12)=-1.557	0.145	T(12)=-0.177	0.862
H4	T(12)=-0.114	0.911	T(12)= 1.396	0.188
H5	T(8,24)=1.000	0.346	*T(12)= 2.840*	*0.015*
H6	T(7,62)=1.589	0.153	T(12)= 0.811	0.433
H7	T(12)= 1.132	0.280	T(12)=-0.622	0.545
H8	T(12)=-0.299	0.770	T(12)= 0.327	0.749

Significant differences were also detected in Health Companion. The excellent usability tasks related to h1-match, spent less energy on the power supply, 199.91 ± 7.19 W. On the other hand, the group of excellent usability tasks related to h3-memory and h6-consistency required more energy from the power supply, 210.20 ± 11.70 W and 208.64 ± 10.71 W respectively. The results are shown below in Table 11.

Table 11 Analysing the effect of usability on power consumption by a T-student test (IV)

	HealthCompanion			
	Monitor		**Power supply**	
	T(df)	*p*	*T(df)*	*p*
H1	T(16)= 0.018	0.986	*T(16)= 2.233*	*0.040*
H2	T(16)= 0.055	0.957	T(16)= -0.366	0.719
H3	T(16)=-0.266	0.794	*T(16)= -2.164*	*0.046*
H4	T(16)= 0.614	0.548	T(16)= -1.910	0.074
H5	T(16)= 0.255	0.802	T(9,26)=1.270	0.235
H6	T(16)= 0.877	0.393	*T(16)= -2.593*	*0.020*
H7	T(16)=-0.497	0.626	T(16)= -1.042	0.313
H8	T(16)=-0.315	0.757	T(16)= -0.471	0.644

4 Discussion

The analysis of the data yielded a set of significant correlations. The main findings are described below. Several tasks were selected to illustrate the results.

4.1 **RQ 1:** *Is a higher score of the usability heuristics related to a lower power consumption of the PC components?*

To answer the research question, the information was separated into PHRs sections where significant correlations were found.

4.1.1 NoMoreClipboard:

A total of 3 correlations stood out among the rest in this PHR, 2 out of 3 were statistically significant.

The first correlation was between h3-memory and power source ($r_s = 0.495, p = 0.044$). NoMoreClipboard had a particular profile interface where detailed patients' health data are depicted. The amount of information presented has an impact on h3-memory in order to start performing the tasks more easily. However, more energy was demanded on the power supply. A particular example of this correlation was found in Task 7, add medication. An important amount of power was demanded to complete the task (193.252 W). Moreover, the mean usability score from the auditors was high (4.3 out of 5).

Users expect a quite simple, intuitively usable and appealingly modern implementation of the interfaces [40]. As an example, search suggestions provides users with information to avoid remembering the whole name of an item to be inputted in a search engine. These algorithms dynamically retrieve, process and present a list of related inputs before to perform the search [41]. The aforementioned feature was implemented in NoMoreClipboard. There was a collection candidates medicines when typing at least two letters in task 7, add medication. MySQL Pattern Matching, MySQL Fulltext Index, Levenshtein Distance and Jaccard Similarity are some of the technologies to develop this feature. They were compared in terms of processing time. The search of the candidate items demands processing power to access the database. The lower processing time, the lower energy that will be spent. The findings revealed that MySQL Fulltext Index provides more accurate search suggestions than other methods and requires less processing time [42].

Another significant correlation in the same PHR was found between h4-minimalist and monitor ($r_s = -0.513, p = 0.035$). It is worth noting that NoMoreClipboard had an opposite design to the minimalist one (see Figure 2). An overelaborated user interface design may lead to more display variations while performing the tasks. Thus, the monitor may demand more energy for the screen changes [43].

That was the case in the way the relatives medical history was presented in task 6, add family history. The amount of energy spent by the monitor when performing this task was 63.109 W. Moreover, the usability score of h4-minimalistic was very low, 2.3. A mosaic with medical data of the family was depicted in task 6. The way of showing the information was poor in terms of minimalist design. Moreover, the power consumption of the display was the highest one found in this PHR. The design of minimalist user interfaces consists of small rulesets, narrow decision spaces and abstract audiovisual representations [44]. A study revealed that real-time minimal displays can noticeably impact the energy consumption of some users [45]. Computers spend most of their energy waiting for an answer from the user. Thus, there must be a trade-off between energy and user response time to enhance energy efficiency. To this end, low-power cache devices were proposed to attain a

Fig. 2 A NoMoreClipboard profile

good balance between both factors [46]. Moreover, minimalist designs reduce time bottlenecks to get a faster response from the user [47].

A moderate correlation appeared with h8-flexibiliy and power supply ($r_s = -0.457, p = 0.065$). NoMoreClipboard is a PHR in which the presence of this heuristic is remarkable. As an example, the information is splitted with thematic icons that have shortcut links to make faster completing the tasks, and going to any of the PHR's sections (see Figure 2). This characteristic can be found in task 1 of the aforementioned PHR, registration. The steps to complete this task are clearly divided into icons and can be filled in at any order. This feature allows to divide the information in different pages, and the users can perform the task in the order they prefer. When users may only have to complete one of the steps in the registration process, potential savings in energy consumption may be achieved.

4.1.2 PatientsLikeMe:

A total of 2 significant correlations were found in PatientsLikeMe. The first correlation appeared between h4-minimalist and power supply ($r_s = -0.479, p = 0.083$). PatientsLikeMe is characterized by a medium complex user interface, which had an impact on the minimalism of the user interface. As a way of example, in Task 18 the privacy policy has a very simple format compared to what is usual. The privacy policy is divided into sections with brief descriptions. Moreover, text chunks can be showed or hidden when users want more detail (see Figure 3). This feature improves minimalism. On the other hand, accessing to the text chunks required more power. The score was 4.5 in h4-minimalist. In addition, the energy consumed by the power supply was 196.449 W.

Data collected from healthcare devices have significant value when it comes to share them between patients and medical doctors [48]. Privacy has always been a concern, especially in the health domain [49]. Privacy policies explain mainly personal data collection and the way it is processed. Originally, privacy policies used to be presented as textual documents. However, the unsuitability of this format in the web portals led to other means of expression [50]. PatientsLikeMe

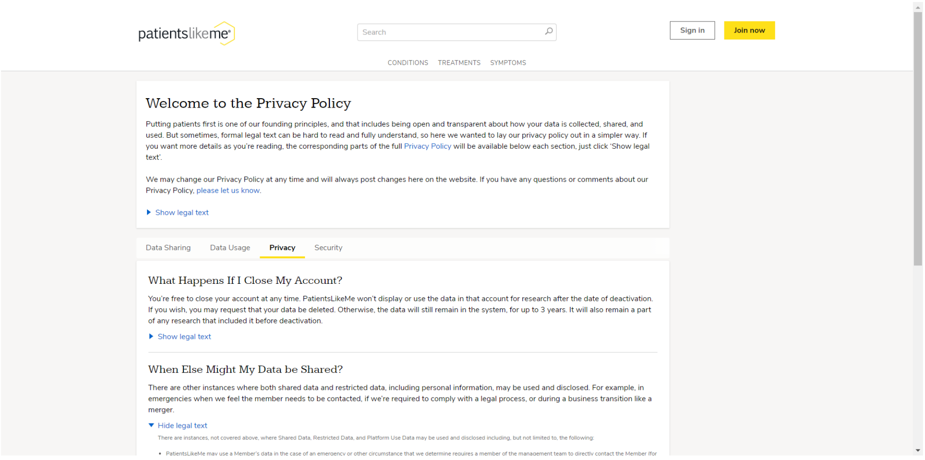

Fig. 3 Privacy policy in PatientsLikeMe

stood out in the minimalism of the privacy policy, reducing at the same time the energy consumption of the power supply. An experiment proved that a model energy consumption of hardware allowed to create energy aware device drivers [51]. These energy models could be applied in cases like PatientsLikeMe. The use of advanced energy consumption prediction models could have an impact in the energy required by the host machines [52]. In this sense, the chunks that are more frequently read, could be detected. Thus, power strategies could be applied when these chunks are showed.

Another important correlation was present between h5-error and power supply ($r_s = -0.638, p = 0.014$). In task 17, send suggestion/contact, there was a form to be filled in to forward a message to the customer service. A set of topics of the message could be selected to address the inquiry more precisely. In addition, access to the FAQs section was provided to clarify the doubts beforehand. These kind of features led to a good usability score in h5-error (mean value of 4), together with a low power demand. Send suggestions required the lowest amount of energy for the power supply in this PHR, 186.956 W.

Error messages are designed to easily draw users' attention and make quick corrections [53]. A total of 4 different error message locations that are frequently found on web portals were tested. The results revealed that the participants detected the error message fastest when they appeared on the right side of the erroneous input field [54]. These results highlights the importance of the widgets' format to avoid repeating steps in the tasks [55]. The sooner a task can be finished, the less amount of power spent. A keystroke-level energy model predicted the user time and system energy consumption to complete a task. This model is based on the psychological theory of human cognitive and motor capabilities. KLEM model allowed to calculate energy profiles of system activities, predicting error rates with the energy profiles of system activities [56]. Models like KLEM can provide valuable information about error widgets to reduce power consumption.

4.1.3 Health Companion:

In the case of Health Companion two strong correlations appeared. The first correlation was related to h1-match and power source ($r_s = -0.481, p = 0.043$). As an example in Task 2, access to the system, the login is clearly marked. The terms used are familiar and the dimensions of the widgets are appropriate (see Figure 4). This allowed to perform the task in less time, saving energy from the power supply. It should be noted that the design of user interfaces of these characteristics favours Fitts' Law, enhancing accuracy when clicking on targets [57]. The average usability score for h1-match when performing Task 2 was 4. Moreover, the power spent in the power supply was 190.114 W.

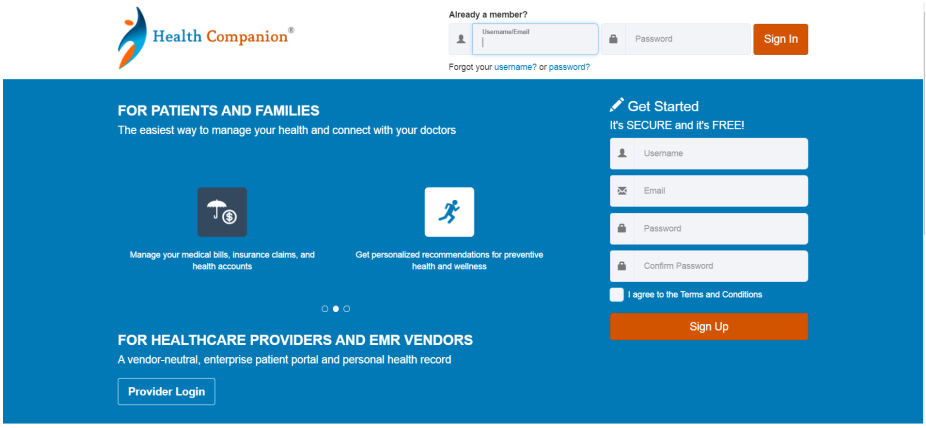

Fig. 4 Login in Health Companion

Most of the techniques proposed in literature for hardware and software energy optimization focus on compute-intensive applications rather than interactive applications [43]. For this reason, the problem of energy saving in current devices is still relevant. Specific amounts of energy consumed by the basic elements of the electronic devices should be considered to quantify energy requirements of the applications [58]. In this vein, energy-adaptive display interfaces were tested. As a result, there was a good acceptance of energy-aware user interfaces [59].

Another important pair of correlation was h5-error and power supply ($r_s = -0.602, p = 0.008$). This correlation also appeared in PatientsLikeMe between the same heuristic and PC component. In the case of task 5, manage permission to 3rd parties, a mechanism to avoid providing access to an external user was restricted. This feature was implemented for error prevention and security purposes. Moreover, less energy was demanded to the power supply. The usability score in h5-error was 4.3 and the power spent in the power supply 187.971 W. As aforementioned, the use of psychological models for human cognitive capabilities can predict execution time for a skilled user [56], detecting where errors in the web portals may happen often [60].

4.2 **RQ 2:** *Is higher usability heuristics score related to lower power consumption of PC components?*

To answer the research question, the information was also divided into sections named according to the PHR in which significant differences were obtained.

4.2.1 PatientsLikeMe:

In this PHR the tasks with an excellent score of usability concerning h5-error spent less energy in the power source than the tasks considered with fair usability. This PHR had a medium complexity interface that presented mechanisms to avoid producing errors as previously stated. Preventing errors or provided with information to perform a task improves usability. The less error that are done, the less steps and time that will be necessary to complete a task. Thus, h5-error heuristic should be taken into account when developing a PHR to maximize power efficiency.

The tasks concerning h1-match with an excellent level of usability spent less power than the fair level usability tasks for the power source. In Health Companion the health data were depicted in a particular way. The data that was related to the same medical area was grouped in square shapes widgets. Organizing the information in this way had a similarity to noting down the data in note cards. Card style can be used as the way of self-expression to attract the interest of the viewer [61]. In addition, the power required is reduced due to the easiness to find the medical information.

5 Conclusions and Future Work

In the general context of software systems development, the requirements engineering discipline plays an important role in making software more energy efficient. Within software engineering, requirements activities are essential to achieve a power reduction when a client application is run in a computer. There is a wide variety of catalogues to take into account right from the scratch the quality requirements such as security and usability. However, the approaches to manage energy efficiency requirements are scarce. Some ways of tackling this problem are focused on systematically eliciting, analysing and documenting power consumption requirements, and including energy sustainability goals in the software engineering process. In the current software development methods the energy requirements are poorly addressed. Consider usability as an attribute related to software energy efficiency may led to mitigate this problematic. A piece of software with a low usability rating normally implies more time interaction for the user, and in turn, the energy consumption can be higher. Software with a high usability characteristic is less likely to stop being exploited prematurely, thus is more durable and generates a low impact on the environment.

From the results collected in the paper the research questions, RQ1 and RQ2, were answered partially. In some cases we were able to confirm that the higher score in usability of the GUI resulted in a higher power reduction. This work generates new results that extend those obtained from a previous study [30]. More effort should be put into investigating the topic of this paper, obtaining a comprehensive set of recommendations for software development. In this sense, a software requirements catalogue that relates the quality factors studied in this manuscript, usability and energy efficiency, could be constructed. Interface design patterns obtained from this study together with those from the aforementioned study are shown in Table 12.

Table 12 Collection of interface design patterns

Heuristic	Pattern	Task	PHR
Previous study [30]			
Consistency	Single sign-on mode	Login	HealthVault
Task migratability	Autocomplete	Information of conditions search	PatientsLikeMe
Observability	Loading icons with linear behaviour	Provide access to external users	Health Companion
Recoverability	Keep the writing in the forms	Contact/propose suggestions	NoMoreClipBoard
Responsiveness	Well balanced GUI	Check profile	HealthVet
Present study			
Memory	Search suggestions	Add medication	NoMoreClipBoard
Minimalist	Avoid overelaborated GUIs	Add family history	NoMoreClipBoard
Flexibility	Split information with thematic icons	Registration	NoMoreClipBoad
Minimalist	Text chunks to be showed or hidden	See privacy policy	PatientsLikeMe
Error	Inquiry topics/FAQs	Send suggestion/contact	PatientsLikeMe
Match	Widgets clearly marked, proper dimensions	System access	Health Companion
Error	Avoid access to an external user	Permission to 3rd parties	Health Companion

In future work, energy consumption data could be analyzed from a new perspective. In this paper, the energy values are averages of instantaneous energy consumption. However, adopting functions with total energy consumption per task could yield new results. This would be done by considering the power consumed during the entire duration of the task. As a result, energy consumption functions would be compared between tasks. In this way, the balance between total energy consumption and task duration could be evaluated for each task and PHR.

The research presented in this manuscript could be further developed. We intend to replicate the experiment with other PC-configurations in the future. Our aim will be to analyze the influence of different PC components on the power consumption. We will seek to perform the tasks in several computers with different internet speeds which may impact on the time required to perform the tasks. Moreover, we will extend our study by addressing non-free PHRs.

In addition, the GUI components that enhance usability could be studied in isolation, considering the energy consumption of each one. An energy efficiency score would be given depending on the amount energy spent by each component. Thus, the components used in the GUI would give an indicative idea of the energy impact produced by the usability levels of the client application.

Compliance with ethical standards

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